

On a Complete Apparatus for the Study of the Properties of Electric Waves

IX. On a complete Apparatus for the Study of the Properties of Electric Waves. By JAGADIS CHUNDER BOSE, M.A. (Cantab.), D.Sc. (Lond.), Professor of Physical Science, Presidency College, Calcutta^[1].

THE work of Hertz and his eminent successors, both here^[2] and on the Continent, has opened out for study a new region of æthereal vibration, bridging over the gap that hitherto existed between the comparatively slow æther vibrations and the quick oscillations which give rise to radiant heat. In the vast range of possible æther vibrations we recognize only a few octaves by our senses; the rest are beyond our perception. Many unexpected properties of these little-known æther waves are now being gradually discovered. Confining our attention to the electric waves, we find that there are many important problems which may perhaps be better attacked with these comparatively slow vibrations; among which may be mentioned the determination of the indices of refraction of various substances which are opaque to visible light, but are transparent to the electric ray; the relation between the dielectric constant and the refractive index when the rates of oscillation are made comparable in the two determinations; the variation of the index with the frequencies of vibration. Then there are the phenomena of double refraction, polarization, and the magnetic rotation of the electric ray; the determination of the wave-length, and other problems of a similar nature.

The fascination of the subject drew me to its study, though the investigations were rendered exceedingly difficult in India from want of facility for making the necessary apparatus. I ultimately succeeded in constructing a few instruments with which I was able to obtain the values of the indices of refraction of various substances for electric waves, the wave-length of electric radiation, to demonstrate the phenomena of double refraction and polarization of the electric rays, and to find out certain substances which act as electric tourmalines. The simplified apparatus with which many of the properties of electromagnetic radiation may be studied is here exhibited. This is a duplicate made by Messrs. Elliott, Brothers, of the apparatus which I brought from India. I also take this opportunity of thanking Mr. Bolton, F.R.A.S., of the Mathematical Instrument Department, Calcutta, for the divided circle in my apparatus.

The following are the experiments which may be carried out with this apparatus:—

A. Verification of the laws of reflexion.

1. Plane mirrors.
2. Curved mirrors.

B. Phenomena of refraction.

1. Prisms.
2. Total reflexion.
3. Opacity caused by multiple refraction and reflexion.
4. Determination of the indices of refraction.

C. Selective absorption.

1. Electrically-coloured media.

D. Phenomena of interference.

1. Determination of the wave-length by curved gratings.
2. Bi-prism experiments.

E. Double refraction and polarization.

1. Polarizing gratings.
2. „ crystals.
3. Double refraction produced by crystals.
4. „ „ other substances.
5. „ „ by strain.
6. Circular polarization.
7. Magnetic rotation.
8. Electro-polariscope and polarimeter.

In the list of experiments above-mentioned, the determination of the wave-length by curved gratings has been carried out with a larger apparatus (*vide* Proc. Roy. Soc. vol. IX., "On the Determination of the Wave-length of Electric Radiation"). Experiments with circular polarization and magnetic rotation and with the bi-prism are still in progress. All the others have been repeated with the apparatus to be described below.

The complete apparatus consists of:—(1) A radiating apparatus emitting electric waves of short length; (2) A receiver used as a detector of electric radiation; and (3) Various accessories for the study of the different phenomena.

I used various methods for the production of oscillatory discharge. One method was to imbed a row of metallic beads, with small spark spaces, in solid paraffin, the end beads being in connexion with the electric generator. Another method was to have the two sparking-balls immersed in kerosene; this is effective, but troublesome. The simplest method, however, is Prof. Lodge's arrangement of two side balls and an interposed sphere.

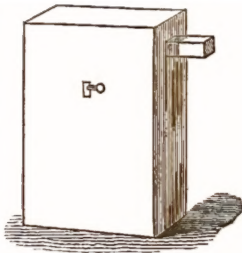
Electric oscillation is produced by sparking between two beads of platinum and an interposed sphere of the same metal. The discharge ceases to be oscillatory when the ball is roughened, and a platinum ball resists, to a great extent, the disintegrating action of the sparks. Two jointed electrodes carry the two beads at their ends. The distance between the beads and the interposed sphere can thus be adjusted. This is a matter of importance, as the receiver does not properly respond if the spark length is too large. It is more convenient to use short electric waves, and these are obtained by making the radiating spheres very small. The shortest wave-length produced is about 6 mm., and the corresponding number of oscillations is about 50,000 millions in a second. The frequency of vibration in this case will be seen to be about thirteen octaves lower than that which produces visible radiation. The intensity of radiation in the above case is rather feeble, and I use in general electric waves of about half an inch in length.

Fig. 1.—The Radiator.



The jointed electrodes carrying the beads are in connexion with a small modified Ruhmkorff's coil, actuated by a small storage cell. The usual vibrating interrupter is generally a source of trouble; the contact points get worn out and the break becomes irregular. The great objection (as Hertz found) to the continuous production of secondary sparks is the roughening of the surface of the radiating ball, by which the spark ceases to be oscillatory. It is very troublesome, in the middle of an experiment, to be obliged to take out the radiator for polishing. The flash of radiation produced by a single break is enough for an experiment, and it is a mere waste to have a series of useless oscillations. In my apparatus for quantitative measurements I have therefore discarded the vibrating interrupter in favour of a simple break-key. To economize space, I wind the condenser (a long strip of paraffined paper with tin foils on opposite sides) round the secondary of the coil, appropriate connexions being made with the interrupting key. The coil and a small storage cell are enclosed in a metal box, in accordance with the precautions which Prof. Lodge had found to be necessary. I used tinned iron in order to screen the space outside from magnetic disturbances due to the making or breaking of the primary circuit of the coil. A sudden magnetic variation disturbs the receiver. The iron box is placed inside a second box of thick brass or copper. These precautions are taken to prevent straying of electric radiation. Through a small opening in the back or side of the box the stud of the press-key projects. In front of the box is the radiator-tube, which may be square or cylindrical. Inside this tube is mounted the radiating originator. A flash of electric radiation is produced by a proper manipulation of the interrupting key. The radiating apparatus may thus be made very small and portable, and requires very little attention. After the storage cell is once charged, experiments may be carried on for days, a flash of radiation being produced at any time by merely manipulating the key.

Fig. 2.—The Radiating Box.



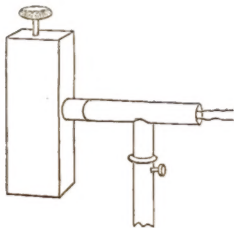
Spiral Spring Receiver.

For a detector of radiation I used a form of Prof. Lodge's coherer. At first I used one made of metallic filings, originally discovered by M. Branly; but great difficulty was experienced in making the receiver respond to different vibrations, and in the capriciousness of its response. The difficulty was still further enhanced when the radiator and the receiver had to be enclosed in narrow tubes to enable angular measurements to be made with any accuracy. It seemed to me that the frequent loss of sensibility might be due to the particles getting jammed together, and the fatigued condition of contact surfaces. In order to avoid this I used a layer of narrow spirals of steel, lying side by side, and rolling on a smooth surface. The points of contact are numerous, and fresh surfaces can be brought into action by a slight rolling of the spirals. By this spiral-spring arrangement the pressure exerted on contiguous spirals is also made fairly uniform.

From a series of experiments carried out to determine the other causes which may be instrumental in producing loss of sensibility, I found that the sensibility of the receiver to a given radiation depends (1) on the pressure to which the spirals are subjected, and (2) on the E.M.F. acting in the circuit. The pressure on the spirals may be adjusted, as will be described later on, by means of a fine screw. The E.M.F. is varied by a potentiometer-slide arrangement. This is a matter of great importance, as I often found a receiver, otherwise in good condition, failing to respond when the E.M.F. varied slightly from the proper value. The receiver, when subjected to radiation, undergoes exhaustion. The sensibility can, however, be maintained fairly uniform by slightly varying the E.M.F. to keep pace with the fatigue produced.

The receiving circuit thus consists of a spiral-spring coherer, in series with a voltaic cell and a dead-beat galvanometer. The receiver is made by cutting a narrow groove in a rectangular piece of ebonite, and filling the groove with bits of coiled steel springs arranged side by side in a single layer. The spirals are prevented from falling by a glass slide in front. The spirals are placed between two pieces of brass, of which the upper one is sliding and the lower one fixed.

Fig. 3.—The Spiral Spring Receiver.



These two pieces are in connexion with two projecting metallic rods, which serve as electrodes. An electric current enters along the breadth of the top spiral and leaves by the lowest spiral, having to traverse the intermediate spirals along the numerous points of contact. The resistance of the receiving circuit is thus almost entirely concentrated at the sensitive contact-surface, there being little useless short-circuiting by the mass of the conducting layer. When electric radiation is absorbed by the sensitive surface, there is a sudden diminution of the resistance and the galvanometer spot is violently deflected.

By means of a very fine screw the upper sliding-piece can be gently pushed in or out. In this way the spirals may be very gradually compressed, and the resistance of the receiver diminished. The galvanometer spot can thus easily be brought to any convenient position on the scale. When electric radiation falls on the sensitive surface the spot is deflected. By a slight unscrewing the resistance is increased, and the spot made to return to its old position. The receiver is thus re-sensitized for the next experiment.

The sensitiveness of the receiver may be increased by a proper adjustment of the E.M.F. acting on the receiving circuit. The receiver at each particular adjustment responds best to a definite range of vibration lying within about an octave. The same receiver could, however, be made to respond to a different range by an appropriate change of the E.M.F.; very careful adjustment of this is necessary to make the receiver respond at its best to a particular range of electric vibration. For simple experiments the adjustment of the receiver is not difficult; but for delicate experiments careful manipulation is necessary.

The proper adjustment of the E.M.F. is effected by taking a derived current from a circular potentiometer-slide, fixed at the base of the galvanometer. A simpler way is to take a U-tube, the two limbs being respectively filled with copper-sulphate solution and dilute sulphuric acid. Mixture of the two solutions is prevented by an interposed plug of asbestos. A rod of copper and a rod of zinc are plunged in the two electrolytes, the whole forming a modified Daniell cell. The cell is shunted by a suitable resistance, the receiving circuit being connected to the ends of the shunt. The current flowing through the shunt, and therefore the derived E.M.F. from its ends, is varied by plunging the rods more or less in the solutions.

The leading wires from the ends of the receiver are enclosed in layers of tin-foil; the galvanometer and cell have a metallic cover with a slit for the passage of the reflected spot of light. The receiving circuit is thus shielded from the disturbing action due to stray radiations.

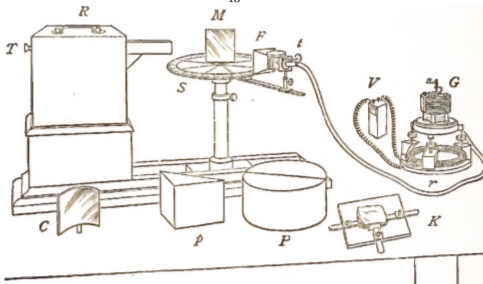
The receiver is provided with a *collecting funnel*. This prevents lateral waves from acting on the receiver. The funnel has two hinged side-doors, by which its area—and, therefore, the amount of radiation collected—may be varied. When angular deviation is to be measured, the doors are made parallel and perpendicular to the layer of spirals. The aperture is reduced, and the receiver then only responds when the funnel points to the direction of the deviated ray.

In polarization experiments it is necessary to adjust the receiver carrying the analyser in a crossed position. This is done by a tangent screw, the rotation of the analyser being measured by means of an index and a graduated vertical disk.

Arrangement of the Apparatus.

The radiating apparatus and the receiver are mounted on stands sliding in an optical bench. Experiments are carried out with divergent or parallel beams of electric radiation. To obtain a parallel beam, a cylindrical lens^[3] of sulphur or ebonite is mounted in a square tube. This lens-tube fits on the radiator-tube, and is stopped by a guide when the oscillatory spark is at the principal focal line of the lens. The radiator-tube is further provided with a series of diaphragms by which the amount of radiation may be varied.

Fig. 4.—Arrangement of the Apparatus. $\frac{1}{10}$ nat. size.



R, the Radiator. T, the Tapping Key. S, the Spectrometer-Circle. M, the Plane Mirror. C, the Cylindrical Mirror. p, Totally Reflecting Prism. P, the Semi-Cylinders. K, the Crystal-Holder. F, the Collecting Funnel attached to the Spiral Spring Receiver. t, the Tangent Screw, by which the Receiver is rotated. V, Voltaic Cell. r, the Circular Rheostat. G, the Galvanometer.

For experiments requiring angular measurement, a spectrometer-circle is mounted on one of the sliding stands. The spectrometer carries a circular platform, on which the various reflectors, refractors, &c. are placed. The platform carries an index, and can rotate independently of the circle on which it is mounted. The receiver is carried on a radial arm (provided with an index) and points to the centre of the circle. An observing telescope may also be used with an objective made of ebonite with a linear receiver at the focal plane. But an ordinary receiver provided with a funnel is all that is necessary for ordinary experiments.

Laws of Reflexion.

Plane Mirror.—A parallel beam is used. The spectrometer-circle is adjusted with the zero division opposite to the radiator. The platform index is turned to zero, and a plane reflector placed on a previously marked diameter at right angles to the index. The receiver is placed, say, at 60° . The platform carrying the mirror is slowly rotated (electric radiation being at the same time produced by interrupting the key), till the receiver suddenly responds. It will now be found that the platform index points to 30° , midway between the radiator and the receiver.

Curved Mirror.—A cylindrical metallic mirror, with a radius of 25 cm., is placed on the platform, with its principal axis coinciding with the platform index. When the radiator is placed at a distance of 25 cm. from the mirror, the source of radiation would be at the axis of the cylinder. The reflected image will now be formed at an equal distance. The receiver mounted on the radial arm (at a distance of 25 cm. from the centre) is placed at a given angle; the platform is rotated till the receiver responds. The index will now be found to bisect the angle included between the radiator and the receiver.

Refraction.

Deviation of the Electric Ray by a Prism.—An isosceles right-angled prism is made of sulphur or ebonite. Parallel beam is used. For showing deviation by refraction one of the acute angles is interposed on the path of the beam.

Total Reflexion.—An interesting experiment on total reflexion is shown in the following way:—The receiver is placed opposite to the radiator, and the prism interposed with one of its equal faces at right angles to the direction of the ray. The receiver will remain unaffected. The critical angle of ebonite being considerably less than 45° , the rays undergo total reflexion. On turning the receiver through 90° it responds to the totally reflected ray.

Opacity due to Multiple Refraction and Reflexion.—An experiment analogous to the opacity of powdered glass to light is shown by filling a long trough with irregular-shaped pieces of pitch, and interposing it between the radiator and the receiver. The electric ray is unable to pass through the heterogeneous media, owing to the multiplicity of refractions and reflexions, and the receiver remains unaffected. But on restoring partial homogeneity by pouring in kerosene, which has about the same refractive index as pitch, the radiation is easily transmitted.

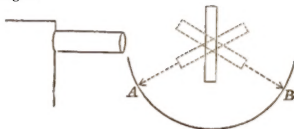
Determination of the Indices of Refraction.—For the determination of the index the prism-method is not very suitable. I found the following to yield good results, the method depending on the determination of the critical angle. Two semi-cylinders of the given substance separated by an air-space are

Fig. 5.



placed on the platform. When the radiator is placed at the principal focus of one of the semi-cylinders the rays emerge parallel into the air-film, and are then focussed on the receiver by the second semi-cylinder. A metallic plate with a narrow rectangular opening is interposed between the semi-cylinders to serve as a diaphragm, and cut off all but the central rays. As the platform is rotated, the incident angle on the plane surface separating the two media is gradually increased till the rays undergo total reflexion. When this is the case the receiver, which is placed opposite the radiator, suddenly ceases to respond. The trouble of following the deviated ray is thus

Fig. 6.

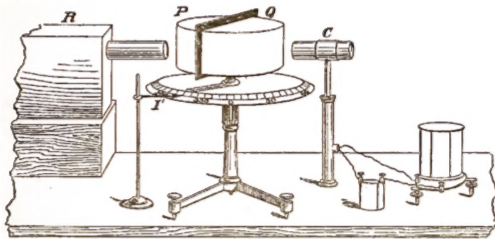


(The dotted lines show the two positions of the air-film for total reflexion.)

obviated; the reading is also well defined as the transition from refraction to total reflexion is abrupt. The index-reading is now taken, and the cylinders rotated in an opposite direction till total reflexion takes place a second time. The difference of readings as given by the index in the two positions is evidently equal to twice the critical angle. Hence the value of the index can easily be deduced.

A preliminary experiment gives the approximate value of the index, from which the focal distance of the semi-cylinder is roughly calculated. The spark-gap of the radiator is placed at this focus, and the experiment repeated. In this way I have determined the indices of refraction of several solids

Fig. 7.—Electric Refractometer.



R, the Radiator. C, the Receiver.

for the electric ray (*vide* "On the Determination of the Indices of Refraction of various Substances for the Electric Ray," Proc. Roy. Soc. vol. lix.). The index of refraction of commercial sulphur is = 1.73; that of a specimen of pitch = 1.48.

Indices for Liquids.—A cylindrical trough is filled with the given liquid; two thin parallel glass plates enclosing an air-space are vertically placed so as to divide the liquid cylinder into two halves. The readings for total reflexion are taken as in the last case. The index for a specimen of coal-tar I found to be 1.32.

Selective Absorption.

A substance is said to be coloured when it allows light of one kind to pass through, but absorbs light of a different kind. If we take into account the entire range of radiation there is hardly a substance which is not, in this sense, coloured. In the spectrum of radiation transmitted through glass, for example, two broad absorption-bands would be observed, one in the ultra-violet, and the other in the infra-red, the electric and the visible rays not being absorbed to any great extent. A brick or a block of pitch would absorb light, but would transmit the electric ray. On the other hand, a stratum of water, though transparent to light, would absorb the electric ray. These substances exhibit selective absorption, and are therefore coloured.

If we take into account the electric radiation only, it would no doubt be found that radiations having different wave-lengths are unequally absorbed by different substances.

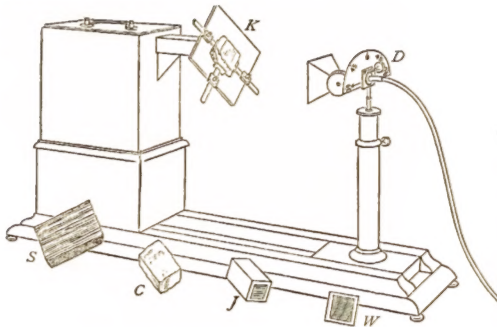
Phenomena of Interference.

Determination of the Wave-Lengths by Diffraction Gratings.—In a paper read before the Royal Society in June last (*vide* Proceedings of the Royal Society, vol. lx.) I have given an account of a method of obtaining pure spectra of electric radiation by means of curved gratings. The experiment was carried out with a large apparatus. The spectrum obtained was well defined, and appeared to be linear, and not continuous. I had not time to adapt the experiment to this small apparatus, but I think it would not be difficult to do so.

Double Refraction and Polarization.

The spectrometer circle is removed, and an ordinary stand for mounting the receiver substituted. By fitting the lens-

Fig. 8.—Polarization Apparatus.



K, the Crystal-Holder. S, a Piece of Stratified Rock. C, a Crystal. J, the Jute Polarizer. W, the Wire-Grating Polarizer. D, the Vertical Graduated Disk, by which the Rotation is measured.

tube the electric beam is made parallel. At the end of the lens-tube there is a slot in which is dropped the wire-grating polarizer. A crystal-holder provided with three sliding jaws is fitted on to the lens-tube, and is capable of rotation round an axis parallel to the direction of the electric ray.

The receiver carrying the analyser is also capable of rotation round a horizontal axis by means of a tangent screw. The angular rotation is measured by means of an index fixed to the analyser, and a graduated vertical disk.

The gratings are made by winding fine copper wire, parallel, round square frames, as used by both Hertz and Lodge. A series of parallel slits cut in a metallic plate serves the purpose very well. Other forms used—the serpentine and the jute polarizers—will be described later on.

The spark-gap is placed vertical, and the polarizer is adjusted with wires horizontal. The emergent beam is now completely polarized, the vibration taking place in a vertical plane passing through the axis.

The analyser fitted on to the receiver may be placed in two positions:—

- (1) Parallel position. When both the gratings are horizontal.
- (2) Crossed position. When the polarizing grating is horizontal, and the analysing grating vertical.

In the first position the radiation, being transmitted through both the gratings, falls on the sensitive surface, and the galvanometer responds. The field is then said to be bright. In the second position the radiation is extinguished by the crossed gratings, the galvanometer remains unaffected, and the field is said to be dark. But on interposing certain crystals with their principal planes inclined at 45° to the horizon, the field is partially restored, and the galvanometer spot sweeps across the scale. This is the so-called depolarization action of double-refracting substances^[4].

Experiments with Wire Gratings.—A Wire grating at 45° interposed between the crossed analyser and polarizer partially restores the field, but ordinary wire gauze does not transmit any radiation, the action of one set of wires being neutralized by that of the other set at right angles.

Double Refraction Produced by Crystals.—The crystals to be examined are mounted on the holder, and properly inclined. Double refraction is shown by all crystals belonging to the Rhombic, Rhombohedral, Triclinic, and Monoclinic systems. The effects exhibited by the following are very marked, small pieces even producing depolarization.

(1) *Serpentine.*—This substance, which appears fibrous, transmits the ordinary and the extraordinary ray, with unequal intensity. A fairly thick piece completely absorbs vibrations parallel to the fibres, and transmits vibrations perpendicular to the fibres. Ordinary radiation, after transmission through a thick piece of serpentine, would be plane-polarized, the vibration taking place perpendicular to the fibres. A thick piece of serpentine thus acts as an efficient polarizer.

There are certain important points in connexion with selective conductivity and the phenomena of polarization by absorption exhibited by certain substances, which will be dealt with in a future paper.

(2) *Nemalite.*—This crystal exhibits this effect in a still more marked degree.

(3) *Tourmaline* also produces the depolarization effect. The difference in absorption of the ordinary and the extraordinary rays is, however, not so great as in the case of light.

(4) *Beryl*, *Apatite*, and *Barytes* are also very good crystals for exhibiting the depolarization effect.

Polarization Produced by other Substances.—I found many other natural substances producing polarization, the most interesting being vegetable fibres. Common jute (*Corchorus capsularis*) exhibits the property in a very marked degree. I cut fibres of this material about 3 cm. in length, and built with it

a cell with all the fibres parallel. I subjected this cell to a strong pressure under a press. I thus obtained a compact cell 3 X 3 cm. in area, and about 5 cm. in thickness. This was mounted in a metallic case, with two openings about 2 X 2 cm. on opposite sides for the passage of the radiation.

This cell was found to quench vibrations parallel to the fibres, and transmit vibrations perpendicular to the fibres. Jute cells could thus be made to serve as polarizers or analysers.

Effect due to Strain.—Could be exhibited by stratified rocks, the plane of stratification being inclined at 45° to the horizon.

Effects similar to that produced by unannealed glass can be imitated by a block of unequally chilled paraffin.

The polarization-apparatus described above may also be used as a polarimeter, the rotation of the analyser being measured by the graduated disk.

1. Read before the British Association at Liverpool, 21st Sept., 1896. Communicated by Lord Kelvin, F.R.S.
[The apparatus described in this communication is founded on Prof. Oliver Lodge's and M. Branly's discovery of the "coherer" for detecting electric waves. The general design of the apparatus, both in respect to generator and receiver, was given originally by Prof. Lodge, and described in his book 'The Work of Hertz and some of his Successors, published by the Electrician Co. in 1894.—EDITORS.]
2. By "here" is meant not only England, but Professor Lodge's laboratory especially, where the paper was read, and where, as is well known, some of the most important investigations on electric radiation have been carried out. For my interest in the subject I owe greatly to Prof. Lodge.
3. See Lodge and Howard, Phil. Mag. July 1889.
4. For a detailed account of experiments on the polarization of the electric ray, I would refer to my paper, "On the Polarization of the Electric Ray by Double-refracting Crystals," read before the Asiatic Society of Bengal, May 1895, and two subsequent papers ("On a new Electro-Polariscope" and "On Double-refraction of the Electric Ray by a Strained Dielectric") published in the 'Electrician,' 27th December, 1895.

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